Use of Guidance and Control Test Cases to Verify Spacecraft Attitude Control System Design

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Extended Abstract

One of NASA's last highly redundant deep space missions, the Cassini spacecraft and the attached Huygens probe, launched atop a Titan 4B on October 15, 1997. During a four-year tour of Saturn and its moons beginning in July of 2004, and during several observations of opportunity along the way to Saturn, Cassini must satisfy stringent pointing performance requirements. To support the Saturn tour trajectory and the pointing demands of its instrument suite, the spacecraft must execute nearly precise trajectory correction maneuvers (TCM) and maintain steady and accurate track of targets exhibiting complex relative motion. A key element in meeting these requirements is the Cassini Attitude and Articulation Control Subsystem (AACS) flight software.

Paramount in the development and updating of flight system software is the need to perform comprehensive testing. In the spirit of the "test it as you fly it" philosophy, the testing must provide an accurate representation of the conditions under which the software will be used during the mission. For the Cassini mission, this strategy was implemented via a set of test beds supporting closed-loop simulation with and without hardware in the loop. For the specific purpose of confirming that the attitude control

software meets its performance requirements, a collection of tests using software simulation of the spacecraft and the deep space environment were developed. These test cases are known collectively as the Cassini AACS Guidance and Control (G&C) test cases.

The test approach for the G&C cases begin with a collection of scenario descriptions covering a range of typical and mission-critical spacecraft scenarios. These scenarios include:

- spacecraft detumbling after spacecraft-launch vehicle separation
- full-sky sun search after a loss of attitude reference
- main engine and RCS thruster trajectory correction maneuvers
- Saturn orbit insertion
- spacecraft detumbling after Huygens probe release
- Huygens probe tracking
- low altitude radar mapping of Titan
- high precision imaging of science targets with the narrow angle camera
- reaction wheel momentum unloading
- data downlink to Earth

Each activity is reproduced as a nominal scenario along with several off-nominal test variants. This provides a baseline confirmation that the mission requirements can be met, as well as insight into the margin available to accommodate stress conditions. One engineer developed both the scenario definitions and the detailed test with peer review by the entire AACS team. Among other things, the detailed scenario descriptions document initial conditions, appropriate spacecraft inertial properties, maneuver scenarios, predicted performance, relevant spacecraft requirements, and pass-fail criteria. Each test scenario is scripted for use in the Flight Software Development System (FSDS) to produce realistic command sequences in the presence of various environmental and spacecraft model conditions. Hosted on Sun work stations, FSDS supplies a Sun™ workstation-based build of the flight software with the inputs needed to simulate the physics and hardware of the spacecraft. Interactively or through scripts, FSDS's TCL command engine accepts the Cassini AACS spacecraft command set as well as special fault injection and environmental disturbance commands.

Each test activity focuses on key capabilities and environmental conditions. The trajectory correction maneuvers, for example, put the thrust vector control algorithm for the 445-Newton engine through its paces with intentional mismatches in onboard parameters. The test cases for low altitude radar mapping of Titan verify that Cassini can satisfy pointing requirements in the presence of external torque provided by various Titan atmospheric density models and spacecraft control authority situations. In each case, simulation models have been developed to replicate the appropriate spacecraft environment.

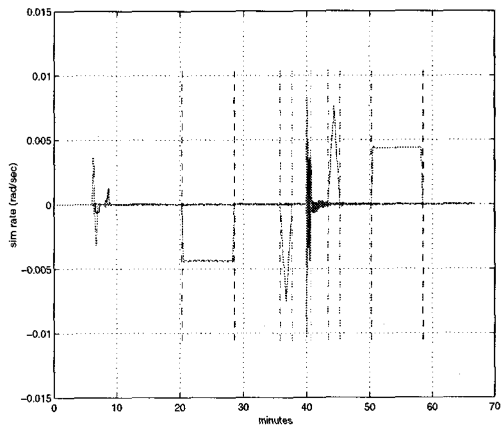

Figure 1. Main Engine TCM Turn Rates

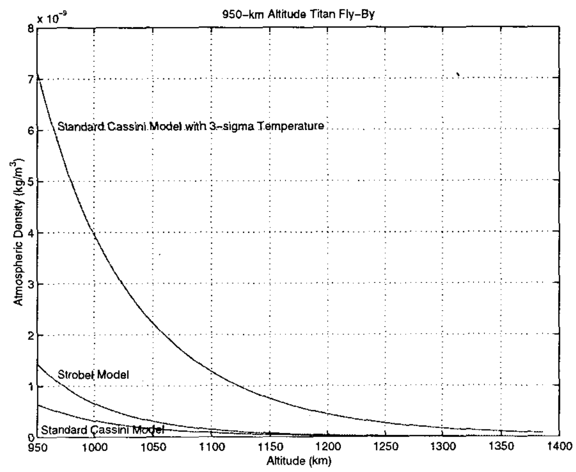

Figure 2. Titan Atmospheric Density Model

Verification of the test results comes through the analysis of MATLAB scripts that were generated from FSDS simulation output. The simulation results are presented to the test team in the form of statistical analyses and plots illustrated with "pass/fail" threshold curves that trace back to Functional Requirements documents. Also, functional sanity checks are included to confirm that no red alarm conditions were detected by the fault protection system.

Throughout the initial software development effort and continuing through the post-launch development phase, the G&C cases have provided an evolving resource for regression testing the flight software. Ongoing updates incorporate the latest environmental models and expand the range of activities and variants examined. For example, new cases based on improved Titan atmospheric density models, targeting with rotating coordinate system commands, new command sequence practices, and additional pointing constraint situations are under development to augment the current suite of tests. Where appropriate, some cases have also been retired (launch scenarios for example).

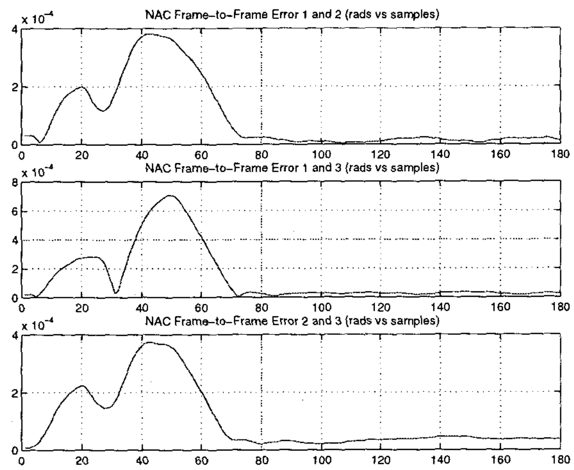

Figure 3. Point-to-Point Tracking Error

As in the Narrow Angle Camera (NAC) pointing stability test case, the test results can be compared directly to flight data collected later. This provides important assurance that the simulation fidelity is sufficient to generate confidence in the results of testing for future mission activities.

From the initial confirmation that the launch load would properly control the spacecraft, to the continued regression testing that verifies compliance of the latest software builds, the Guidance and Control tests ensure continued mission success. The Cassini team believes that the excellent behavior of the spacecraft to-date has justified the time and resources invested to develop and maintain this tool.